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ART. V. — *The American Ephemeris and Nautical Almanac for the Year 1867*. Published by Authority of the Secretary of the Navy. Bureau of Navigation, Washington. 1865.

THIS volume is the thirteenth of the series which was begun in 1852 by the publication of the Ephemeris for 1855. These publications were authorized by act of Congress in 1849, and the work was placed in charge of Admiral (then Lieutenant) C. H. Davis. With that zeal in the cause of science for which many officers of the United States Navy have been distinguished, Admiral Davis undertook the difficult task of giving the materials and form of this work such a value as should not only adapt it to the needs of the Navy, hitherto dependent on a foreign country for so important a part of its equipment, but should adapt the work also to the scientific wants of the country, and make it worthy to take the place of the British Nautical Almanac in our geographical surveys and in the numerous observatories which have been established in this country. By the aid of our most skilful astronomers, and especially through the co-operation of Professor Peirce and Mr. Sears C. Walker, the more serious difficulties were surmounted; fundamental tables were prepared from the best determined astronomical data, and a corps of computers was trained for the work.

To appreciate adequately the value of this important enterprise some account of the history and use of such publications will be of service.

The principal nations of Europe have for two centuries given public support to the cultivation of the science of astronomy, as well as of the art of navigation; and this support was the more earnestly and generously given, when it became evident, near the close of the seventeenth century, that the most refined and complete results of astronomical research could be made directly and in the highest degree serviceable to the needs of the navigator. The celebrated problem of finding the longitude at sea by astronomical means, arose from the insufficiency of the magnet for guiding the navigator with the requisite degree of certainty on the pathless sea. By astronomical determinations of latitude, and a careful observation of the course of the ship

by means of the magnet, and the rate of the ship's sailing by means of the log, navigators had been able to estimate rudely their positions on the sea, and the relative positions of distant ports, headlands, and islands. But the insufficiency of these means, when the "dead-reckoning" was interrupted by storms or disturbed by sea-currents, was at all times aggravated by the uncertainty of the magnet itself, which points rarely to the exact north, and deviates in different parts of the earth's surface by different amounts from the north, and varies in direction from time to time in the same locality. The laws of these variations have been carefully studied, yet at the present day less is known about the complex phenomena of magnetic variation than was then known (two centuries ago) about the complexities in those movements of the heavenly bodies which astronomers have since completely unravelled and reduced to calculation.

While astronomical observations afforded direct and simple means of determining the latitude of any place, and the distance in a north or south direction from one place to another on the earth's surface, means were still wanting for independent determinations of longitude, and the distance from one place to another in an east or west direction. As the tables afforded means for determining the latitude and local time of any place by observations of the sun, it was seen that, if this local time could be compared with that of any fixed place of reference, the port of departure for example, then the problem of longitude would be solved. For this purpose sea-clocks, or chronometers, were invented, to be carried in the ship, and regulated to keep the time of the port of departure, or some standard meridian of longitude. But as these clocks could not be secured from the accidents and variations to which long voyages exposed them, their indications could hardly be trusted more than the use of the magnet in "dead-reckoning," unless some means could be devised for testing and correcting them from time to time. To accomplish this end—to determine by astronomical means alone, at any time, and at any place on the earth's surface, the local time of the standard meridian of longitude—has been the aim steadily pursued by practical astronomy down to the present time.

For this purpose the famous Royal Observatory was estab-

lished at Greenwich, and those illustrious observers, the Astronomers Royal, were in succession severally commissioned and expressly commanded each "to apply himself with the utmost care and diligence to the rectifying the tables of the motions of the heavens, and places of the fixed stars, in order to find out the so much desired longitude at sea, for the perfecting the art of navigation."

The labors of the earlier Astronomers Royal, extending through nearly a century, were finally crowned with a partial success, and the celebrated Dr. Maskelyne devoted his genius and energy to making this success practically available to the art of navigation ; and his efforts resulted in the establishment of the English Nautical Almanac, the first volume of which was published in 1766 for the following year.

The long-continued series of accurate observations and measurements made at the Greenwich Observatory have become so famous for their value to theoretical astronomy, have led to so many brilliant discoveries, and have been so long regarded as the common property of the scientific world, that the purpose for which this Observatory was primarily established by the eminently practical English nation — the perfecting the art of navigation — is almost lost sight of. This purpose was partially accomplished in the establishment of the English Nautical Almanac.

The tables which the Greenwich observations were designed to perfect were derived from those mathematical theories of the movements of the heavenly bodies which astronomers had elaborated from the whole course of observations from the earliest to the latest records, and had finally greatly improved and enlarged by the mathematical development of the Newtonian theory of gravitation. To adapt these theories to an accurate representation of the positions of the heavenly bodies observed from time to time, to embody them in tables for facilitating computation, and finally to *predict* from them future positions with sufficient accuracy for nautical purposes, were the problems of nautical astronomy.

From such predicted positions, made for equal intervals of time, and arranged in tables called *ephemerides*, all other astronomical predictions are derived ; such as eclipses of the sun

and moon, the occultations of the stars by the moon, the passages of any heavenly body over the meridian of any place, the apparent distances of the moon from other luminaries, and many other phenomena useful to the navigator, the surveyor, and the astronomer.

Such ephemerides, or tables of position, predicted several years in advance for the sun, the moon, the planets, and the principal fixed stars, together with the "lunar distances," and such special phenomena as are of chief use or interest, form the principal contents of a nautical almanac, and their value to the navigator or astronomer depends entirely on the accuracy of the tables from which they are derived.

As the moon moves with a comparatively great rapidity among the stars, its constantly varying relative positions are used as *time-signals*, predicted beforehand and observed by the navigator or astronomer in the various forms of lunar distances, occultations, eclipses, and meridian transits or culminations. Accurate tables of the moon are thus of primary importance in the construction of a nautical almanac for the solution of the problem of longitude, and nearly a century elapsed from the first proposal of the problem before lunar tables of sufficient accuracy were produced.

Such, however, has been the subsequent progress of astronomy, that the lunar tables now used in the construction of the American Ephemeris, as well as those now employed in Europe, have more than twenty times the accuracy attained in those which were first used for the British Almanac. At first, the navigator was fortunate if he determined his position at sea within one degree of longitude, or sixty nautical miles. With his present facilities, he can fail to determine his position within three miles only by the imperfection of his instruments, or by errors in their use.

This surprising progress in astronomy, for which the present century is especially distinguished, is in great measure due to the continuous publication of the British Nautical Almanac, and of similar works on the continent of Europe. For, important as the Almanac was to the navigator, and indispensable as it soon became, it was quite as useful to the astronomer. Not only was the observer saved much labor and watching by the

predictions in the pages of the Almanac of the phenomena to be observed, but sources of error, both in theory and in observation, were easily detected, and improvements in astronomical tables greatly facilitated. It was by comparing the observed places of the planet Uranus with its predicted places in the Almanac, that those discrepancies were noticed which guided astronomers to the discovery of the new planet Neptune on the confines of the solar system, whose influence on the motions of the planet Uranus betrayed its existence, and led to its discovery. In this, and in many other ways, the Nautical Almanac repaid the debt it owed the astronomer, and received again new and improved means of usefulness; thus serving at once the noblest of the sciences and the most useful of the arts. No ship at sea and no astronomical observatory can dispense with the Nautical Almanac. The numberless minor observatories in Europe and America complete their equipment with it, and become serviceable to the progress of astronomy, with its aid. All geographical and nautical surveys require its use, and depend for their value on its accuracy.

A few years before the establishment of the Observatory at Greenwich, the French government founded the Royal Observatory at Paris, and a few years later, 1679, the publication of the French Almanac, the *Connaissance des Temps*, was begun, at first, under the direction of the French Academy of Sciences, but afterwards, when its utility to navigation became a prominent object, it was placed under the direction of the *Bureau des Longitudes*. Several other European states have, from time to time, established and continue the publication of almanacs and ephemerides, both in connection with public observatories and for use at sea,—namely, Prussia, Sardinia, the Roman States, Spain, and Portugal.

The accumulation of astronomical knowledge during the past century has been so rapid, and improvements in the arts of observation and computation have been so great, that frequent improvements in the tables used for the preparation of Almanacs have been demanded, both for the needs of practical astronomy and to render the increased knowledge available for nautical purposes; and these improvements have in some cases been so long delayed as to render the Almanac almost useless

to the astronomer, and only a miserable necessity to the navigator.

The *Connaissance des Temps*, for instance, was greatly improved under the superintendence of the astronomer Lalande in the last century; but from that time the work had remained substantially as he left it, even down to our own times, when, in the volume for 1862, the long needed improvements in the lunar ephemeris were introduced. In other respects, however, the work still remains as deficient as when, in 1856, Le Verrier announced in the French Academy that it had been for a long time of no scientific value. This charge against the *Connaissance des Temps* was repeated so late as 1860, when Le Verrier again called the attention of the Academy to its insufficiency and want of accuracy, remarking that “The *Connaissance des Temps* is no longer of use to astronomers. A fundamental reform is urgent, which shall raise it from its inferiority as compared with foreign Ephemerides.” (*Comptes Rendus*, No. 6, 1860.) To these charges the only response which could be made in behalf of the *Bureau des Longitudes* was the insufficiency of the pecuniary means which the French government had appropriated for its support.

During the lifetime of Dr. Maskelyne, numerous changes were made in the tables used in the preparation of the English Nautical Almanac; but from the time of his death, 1811, till very recently, only two important changes in astronomical tables had been made,—the introduction of the French tables of the moon (Bürckhardt’s) in 1821, and of the Italian tables of the sun (Carlini’s) in 1834.

In the year 1830, the construction of the Almanac was found to be so defective, that the subject was referred by the Commissioners of the British Admiralty to the Astronomical Society, requesting that body to consider what improvements could be made. The council of the society presented their report upon the subject the same year. This was immediately approved by the Admiralty, and the proposed changes in the form of the Almanac were carried into effect in 1834. From that date till very recently no material changes were made.

In the important matter of lunar tables no change was made in 1834, although the researches of geometers had already

brought the lunar theory to a much greater degree of perfection than belonged to the tables then in use; and the French, German, and English Almanacs continued to use the obsolete tables of Burckhardt long after the advance in practical astronomy and the requirements of nautical astronomy had rendered their further employment inexcusable.

Accurate determinations of longitude depended at that time chiefly on the perfection of the lunar tables, yet the tables in use were serviceable only for the approximate determinations of the positions of ships at sea. The importance of greater accuracy cannot be better expressed than in the words of the committee of the very council that proposed the changes just referred to.

In their report this distinguished committee expressed

“their decided opinion, that it is not by the mere helps with which the seaman is furnished for the purpose of determining the position of his vessel at *sea*, that the full intent and purpose of what is usually called *nautical* astronomy are answered, since this object is a *part* only of that comprehensive and important subject. An equally important and more difficult portion of it consists in the exact determination of the position of various interesting points on the surface of the earth (equally essential and almost solely applied to the purpose of *navigation*), — such as remarkable headlands, ports, and islands, together with the general trending of the sea-coast between well-known harbors, — and which may properly be designated by the name of *nautical geography*; this can only be effectually and properly executed by methods not available on board a ship, and by delicate instruments placed firmly on solid ground. And the observer in such cases requires all the astronomical aid which can be afforded him from the best tables, arranged in the most convenient form for *immediate* use. This was evidently Dr. Maskelyne's view of the subject, when he first proposed the formation of the Nautical Almanac, as appears from his ‘Explanation and Use of the Articles’ annexed to that work; and the propriety and accuracy of his opinion have been confirmed by the repeated wants and demands of those distinguished navigators who have been employed in several recent scientific expeditions. There are, moreover, many individuals in various parts of the world attached to the science of astronomy, who, by the encouragement and facilities thus given, render considerable assistance to the improvement of astronomy and geography by their exertions; and neither private nor national observatories, on which many thousands are annually expended, can proceed with activity or good effect, unless some aid of this kind is afforded them.”

The United States Coast Survey is an example of the scientific department in nautical astronomy referred to in the above extract. This Survey labored under great disadvantages, on account of the imperfections of the British Almanac during the long time it was obliged to depend on a foreign Ephemeris. Many observations of "moon culminations" made on the Pacific coast for determinations of longitude were laid aside "for want of moon's places more reliable than the British Almanac can give us." (Letter of A. D. Bache, Superintendent of the United States Coast Survey, to the Superintendent of the Nautical Almanac, 1851.) Expensive chronometric expeditions were undertaken for the same reason, to determine by chronometers alone, and without the aid of lunar observations, the difference of longitude between our eastern coast and the western coast of Europe.

In this condition of national dependence on an inferior foreign Ephemeris, the design of establishing an American Ephemeris was favorably entertained by Congress. In other departments of astronomy, America had already achieved great distinction. The establishment of the National Observatory and of the Coast Survey; the achievements of many private observatories, and those improvements in means of observing, which have been adopted in foreign observatories under the name of the "American Method"; the success of American mathematicians in the most recondite researches, by which America has shared with Europe the glory of the most famous discoveries in the present century,—such examples of the independent cultivation of astronomy in America rendered our dependence on a foreign Ephemeris an anomaly and a disgrace. When, moreover, we consider the chief and indispensable uses of the Nautical Almanac, and that independence of foreign nations in all practical matters which every American has at heart, it is strange that our navy and merchant marine should have been left so long dependent on their rivals for the means of navigating the seas on which they aspire to pre-eminence. It was as if our navy had been armed with foreign ordnance, and our merchant-ships equipped in foreign dockyards. In our present relations to foreign nations these considerations are of special significance.

In the preliminary preparations for publishing the American Ephemeris care was taken to improve upon the form and construction of foreign almanacs, as well as upon the tables and other data. For a clear statement and unprejudiced estimate of these improvements, we will quote the words of the Rev. Robert Main, late President of the English Royal Astronomical Society. Writing for the *Encyclopædia Britannica* soon after the publication of the American Ephemeris was begun, this distinguished astronomer says (Vol. III., Art. *Astronomy*):—

“Very recently an American Ephemeris and Nautical Almanac has appeared, which promises to be of great service. It is printed in a large octavo, and is published under the authority of the Secretary of the Navy. It is at present under the superintendence of Lieutenant C. H. Davis, U. S. N., the theoretical part being placed under the special direction of Professor Peirce of Harvard College, Cambridge.

“This work does not copy implicitly any existing Nautical Almanac, but, retaining what is best in our own and others, modifies the arrangement in a way which promises to be more generally convenient. One great peculiarity in this work is the separation between the part designed exclusively for the purpose of navigation, and that which is generally useful for the theoretical or practical astronomer.

“In the second part the places of the fixed stars and the planets are referred to the meridian of Washington, and in the computations the best elements at present known are scrupulously employed. Thus, for the star corrections, Peters’s constants of precession, nutation, &c. have been adapted to Bessel’s formulæ; and with regard to the lunar computations, the elements are based on Plana’s theory, but include Hansen’s inequalities and secular changes of the mean motion and perigee, and Airy’s corrections of the elements derived from the reduction of the Greenwich observations. For the planetary computations, the latest corrections of the elements of each planet have been employed. For Mercury, Leverrier’s theory has been used (*Conn. des Temps* for 1848); for Venus and Mars, Mr. H. Breen’s corrections have been applied to Lindenau’s elements (*Memoirs of Royal Astronomical Society*, Vols. XVIII. and XX.); for Jupiter and Saturn, Bouvard’s tables have been used, with some changes, and Bessel’s value of the mass of Jupiter is employed; for Uranus the elliptic elements of Bouvard are used as the basis, with Leverrier’s corrections and perturbations caused by Jupiter and Saturn (*Conn. des Temps* for 1849), and with Peirce’s corrections and perturbations arising from the action of Neptune; finally, for Neptune, Peirce’s theory and Walker’s orbit have been used in the construction of the Ephemeris.”

Such are the many and important improvements introduced in the American Ephemeris. Of the esteem in which this enterprise was held by the English astronomers, very gratifying proofs were received by the Hon. J. P. Kennedy, late Secretary of the Navy, under whose authority the publication of the American Ephemeris was conducted. While in London, in 1857, this distinguished gentleman was invited to attend the annual visitation of the Greenwich Observatory by the Astronomical Society, where, among many commendations of the organization and efficiency of the scientific departments of our Navy from members of the Society, he had the gratification to receive from the Astronomer Royal "generous and earnest praise of the great merit of our Almanac," of which he said, "It is very admirable, and does great credit to the science of your Navy."

The superiority of the lunar tables prepared under the direction of Professor Peirce for the use of this Almanac rendered its practical value more prominent even than its general scientific merit. Numerous tests of their accuracy have been made, with the most gratifying results. While these tables were in the course of preparation, the Superintendent of the Nautical Almanac was authorized to publish his predictions and elements of the total eclipse of July 28, 1851, for the express purpose of testing the accuracy of the new tables. From observations of this eclipse, made at Cambridge, the British Almanac was found in error eighty-five seconds, and the American Almanac only twenty seconds. From Washington observations, the British Almanac was found in error for the beginning of the eclipse seventy-eight seconds, and for the end sixty-two seconds. The American Almanac was in error for the beginning only thirteen seconds, and for the end only one second and a half. Where the eclipse was total, and where, for this and other reasons, the test was more rigid and conclusive, the result was still more gratifying and decisive as to the superiority of our own lunar tables. The same tables were used in the French and Prussian Almanacs as in the British, and the errors were, therefore, the same. The errors of the old tables exposed in this eclipse may give rise to an error of from fifteen to twenty miles in the determination of the longitude at sea by

means of lunar distances, and to an uncertainty of twice that amount. The possibility of so great an error arising from this source was removed in the American Ephemeris. Before the new tables were completed, important corrections were introduced, which rendered them still more exact, and from tests by meridian observations, made several years later, these tables were found to be sufficiently accurate for the most refined determinations of nautical astronomy. These later tests were made in the office of the Nautical Almanac by Professor Newcomb, by comparing the American Lunar Ephemeris for the years 1856, 1857, 1858, with Greenwich observations. These comparisons were communicated by the Superintendent of the Almanac to the *Astronomical Journal*, and were published in Nos. 129 and 142. They show that the mean error of the tables is quite within the limits of errors of observation, and less than one fourth the error of the tables then used by other almanacs. Concerning these observations Sir J. W. Lubbock says (*Memoirs of the Royal Astr. Soc.*, Vol. XXX.): "The errors of the observations of the moon at Greenwich vary up to $\pm 6''$, and the small differences which exist between the place given by the American tables and the observations at Greenwich are due as well to the errors of the observations as to the errors of the tabular places. This is confirmed by the extreme irregularity of the differences. And it should be remarked, that the large differences which occasionally occurred before have been entirely got rid of by the American tables." And again he says: "As it appeared to me that astronomers would view with greater confidence a comparison of places given by the American tables, made by persons who could have no interest in enhancing their value, I made application to Mr. Hind, the Superintendent of the [English] Nautical Almanac; and, in consequence, he directed Mr. Farley to procure places of the moon from the American Almanac, and compare them with the observations made at Greenwich for the years 1856, 1857, and 1858; and as Mr. Hind has kindly allowed me to publish them with this paper, any one can see at once how extremely accurate the places given by these tables are, and how much more so than places given by Burckhardt's tables."

In consequence of this great inferiority in the tables of Burck-

hardt, which had been used for more than forty years by the British and other European Almanacs, they were at last, very recently, discarded, and the new tables of Professor Hansen, published by the Board of Admiralty, were introduced. Ephemerides prepared from these tables first appeared in the British and French Almanacs for 1862. From such tests as have been applied to them in the National Observatory and in the office of the Nautical Almanac they show but slight improvement upon the American tables; the apparent "probable errors" of the two Ephemerides, as tested by observations made at Washington in 1862, being in the ratio of eight to nine. In both comparisons, however, the magnitudes of the apparent errors bear such relations to their relative frequency as to indicate that they are chiefly composed of errors of observation. In the Ephemerides of later years there is an increase in the magnitudes of the greatest discrepancies; and though the test of observation has not yet shown any decisive or important inferiority in the American tables, yet the more elaborate and more recent investigations embodied in Professor Hansen's tables make it probable that at some future day the former will be superseded either by the latter, or by new tables which shall incorporate still better astronomical determinations. At present, both Ephemerides are as perfect as nautical uses require, and are vastly superior to the tables they have superseded.

Modern observations have shown that material corrections are required in the tables of most of the planets, and a systematic revision of the elements and theories of the four outer planets, Jupiter, Saturn, Uranus, and Neptune, was accordingly undertaken several years ago by the Nautical Almanac, under the direction of Professor Peirce; and considerable progress in this work has already been made.

The present Superintendent, Professor Winlock, has added much to the astronomical value of the Almanac, by increasing the number of the ephemerides of the fixed stars, in the volume for 1865; and in the volume for 1867, a list of occultation phenomena is given for the year 1866, to facilitate the geographical exploration of California and the adjacent territory.

The Almanacs of all maritime nations are designed to con-

tain all that can be of importance to nautical astronomy, but in other respects they have each an individual character, and are devoted to such special service to astronomy as each can best render. Thus the *Connaissance des Temps* has always been the vehicle for the publication of some of the most valuable papers of the French astronomers. One of the objects of the Prussian Almanac, the Berlin *Jahrbuch*, was "to obtain a repertory for all observations, information, remarks, and treatises connected with astronomical science." The Milan Ephemeris contains many valuable observations and papers of the Italian astronomers. The American Ephemeris has already published valuable papers, — two of great practical importance in navigation, and another of great use to astronomers in facilitating the computation of planetary perturbations. Even the nautical part of the Almanac requires, in one respect, different tables for different nations. For although the subject of the tides is an astronomical problem, yet geographical data are necessary to render accurate predictions possible. From the times of the occurrence of high tides, as given in the British Almanac for British ports, only approximate predictions can be made for the American Atlantic coast, while the tides on the Pacific coast are quite distinct and peculiar. Tide-tables have accordingly been prepared, for the use of navigators, from the Coast Survey observations, by Professor A. D. Bache, the Superintendent. These are prepared for the principal ports on our Atlantic and Pacific seaboard, and published with directions for their use in the nautical part of the Almanac.

To support the publication of works like these, which are not only of great scientific value, but of material importance to the useful arts and industries, ought to be regarded not merely as creditable to the government, but as a peculiarly incumbent duty; since a public patronage is especially demanded for the furtherance of such enterprises as cannot command the resources of individuals by the inducements of profit or honor, but which are none the less important to the uses of life and the advancement of civilization. And in the performance of this duty the government ought to consider, beside the immediate wants of the public service, those ultimate utilities of science to the welfare of mankind, of which the history of Astronomy affords so signal an example.